Attachment 1
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White Paper: High Accuracy LOcation (HALO)

V.1

Proprietary to:
Skybridge Spectrum Foundation
University of California - Berkeley

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1. Executive Summary

We propose to construct a fundamental building block for a vision that enables our transportation future, be it vehicle-highway automation, novel concepts in electrification or active safety. Specifically, we wish to systematically research and in the end, produce the next generation in vehicle positioning. To our way of thinking, this is High Accuracy Location (HALO). Moreover, to research HALO requires the skills, expertise and interests of our highly-qualified team: a visionary and 'can do' State DOT (Caltrans), pre-eminent transportation applications research expertise (University of California PATH Program), world-class systems engineering and signal processing expertise from Berkeley's CEE Systems program, EECS departments, the Satellite Navigation and Positioning laboratory of the University of New South Wales, DSRC communication platforms from Savari Networks, and a philanthropic foundation dedicated to cost sharing its precious assets – most specifically, dedicated spectrum it owns *expressly for the public good* – to HALO. In particular, the Skybridge Spectrum foundation proposes to gift 33% of project costs as cost-share to enable the federal vision.

While one aspect of our approach*, use of networked or wide area communications to deliver positioning correction via a host of augmentation means*, will leverage our resources and knowledge we are at our core a transportation applications-oriented research team committed to providing an evenhanded and thorough evaluation of potential HALO approaches. Our proposed approach, therefore, is to systematically examine the techniques enumerated below in the first twelve-month segment, then recommend a best candidate for more in-depth and advanced research. Specifically, we have structured the work plan into three tasks:

- Task 1 Accuracy Requirements on HALO – to address the challenge of year 1 of quantifying the positioning accuracies and reliabilities required by the advanced safety systems mentioned in the BAA, synergistic programs such as VII and Safetrip-21[1], and other federal initiatives such as E-911.
- Task 2 Nationwide Positioning Infrastructure Cost Assessment – to address the challenge of estimating the geographical extent of the new infrastructure. We seek to do this without driving all the roads in the country as has been done at considerable cost by the mapping companies. We see estimating the road area where GPS and its derivatives fail to meet safety system requirements, as the first step to estimating the amount of national investment required to make positioning services available everywhere for safety. Since almost all Global Navigation Satellite Systems (GNSS) work by communications in some spectrum between infrastructure and receiver, we also propose to deliver a national spectrum plan, addressing the challenges of nationwide inter-operability and reliable communication in safety-critical situations without excessive licensing or spectrum usage fees, or excessively low power operation.
- Task 3 Build and Test the most viable new positioning technology – to address the challenges of quantifying state of the art technologies such as GPS+WAAS, GPS+RTK, pseudolites, and RFID in real driving conditions

[1] http://www.path.berkeley.edu/Gems.htm, www.viicalifornia.org

on real roads and fusing them into a common system delivering safety with different technologies in different places with reasonable cost in vehicle and infrastructure.

Task 1 will be completed in the first 12 months while tasks 2 and 3 span both years with a decision gate in-between. In the first segment task 2 will produce the models and we will validate them with GPS data coming in from our SafeTrip-21 field test. After the models are validated we propose to use them on the large-scale in the second year to estimate investment to cover a significant national sub-region such as the San Francisco Bay Area. Likewise, in the first 12 month segment of task 3 we propose to test the performance of current technologies and obtain a baseline, while simultaneously designing and simulating our innovative ideas for fusing them into one system. With the results as decision gate, we propose to prototype and cost the winning solution in the second year.

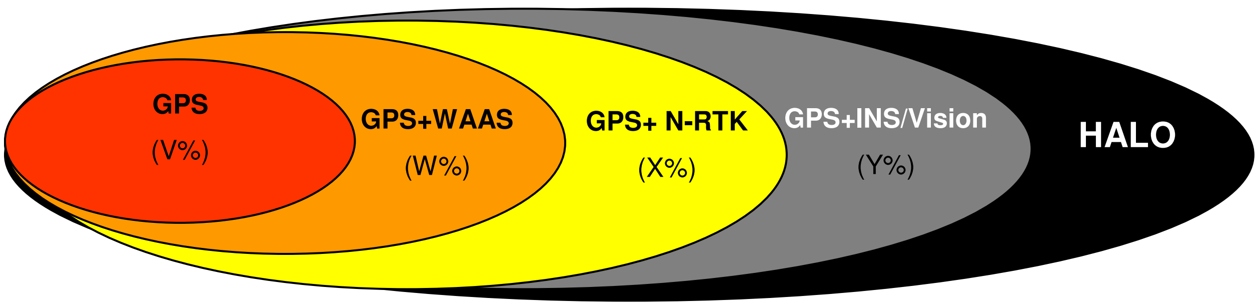


Figure 1. The basic approach to precise positioning for safety nationwide

We approach the challenges in the three tasks through systems engineering in the large-scale (tasks 1 and 2) and innovative technology development in the small-scale (task 3). Figure 1 illustrates the systems engineering approach. Suppose GPS is accurate enough for precise positioning on V% of the nations roads, GPS+WAAS in the market does another W%, emerging GPS + Network RTK adds another Y%. To a first approximation, V+W+Y can be seen as that percentage of the national roadway always exposed to 5 or more satellites at all times[2]. Of the remaining road segments, i.e, segments falling below the 5 satellite threshold, some are small enough for a vehicle to pass without losing precise positioning by GPS/INS/Vision integration (22). Then the DoT dollar, or new national positioning investment dollar, needs to cover the road area percentage 100 – (V+W+X+Y). The smaller the new investment area, the "dark area" marked HALO in figure 1, and the cheaper the technology required to cover it, the more attractive the new positioning investment - a big bang for the small buck. This is the expected impact of this research - the case for federal investment on precise positioning for the nations roads.

This requires quantification of required positioning accuracies (task 1) and the use of these requirements to estimate the percentage of national roadway on which these requirements may not be met by the GNSS market (task 2). We will attack the challenge of task 1 by relating position accuracy to the timeliness of the warning or control and then invert the model. This approach has worked for forward collision warning (10) in a project led by the PI of this proposal. Our research will extend these results to other collision warning and control problems such as intersection collisions,

[2] Roughly a mask angle of 45 degree or less after occlusion by trees or building.

automated longitudinal and lateral control. This task will also deliver a methodology to identify high collision concentrations on roadways and a case study applying it to the Bay Area.

The mapping companies have driven the nation's roads. In spite of this, the data needed to identify GPS gaps does not exist. We propose to estimate 100 – (V+W+X+Y) without driving all the nation's roads. Instead, we propose a random sampling methodology on GIS maps fused with a PDOP coverage model. Basically, GPS precision is related to satellite visibility (see for example (11) by the PI). The satellite visibility is related to the mask angle. The mask angle is related to height of roadside buildings and trees. The idea is to model these relationships and apply them to GIS maps we have found with the necessary information. This task will deliver a dark area estimation tool in ArcView in year 1 and a case study estimating the dark area in the San Francisco Bay Region in year 2. The second deliverable of this task will be a spectrum plan. This will be delivered in year 2. Products such as GPS-RTK or network-RTK, or augmented GPS, rely on wirelessly transmitted corrections. Thus the infrastructure must have a spectrum plan showing that the corrections can be transmitted anytime and anywhere for public safety nationwide. Moreover, HALO as discussed in Task 3 will also require wireless communication to work in the dark areas. Finally we will deliver a dark area cost estimate in year 2 based on the results of task 3.

Finally cost depends on the dark area technology solution (task 3). There are several challenges here. Current pseudolite systems require precise initialization and highly sophisticated signal processing to overcome multipath (1) and achieve clock synchronization (2) (3). We have several ideas to overcome these problems such as augmenting pseudolite designs with RFID readers and tags (29), and phased array antenna's used to estimate angle of arrival (4)(28). This relaxes the picosecond clock accuracy requirements though it does require more precise phase measurements. One approach to this problem is super-resolution sampling (5) and the other virtual phased arrays (4)(28). The second challenge is an in-vehicle receiver able to operate the multiple RF-front ends and DSP implied by figure 1, i.e., positioning with different technologies in different places, while keeping the receiver cheap. We approach this challenge by prototyping on software defined radio.

Therefore HALO will take best-of systems engineering principles: we will work with project teammates to include FHWA to determine Concepts of Operations (ConOps) and generate system-level requirements and then the ConOps (task 1); we will then construct an evaluation methodology (task 2) and prototype to measure actual performance vis-à-vis these requirements (task 3). The workplan fits directly into the *next generation vehicle positioning* topic meeting the following research needs identified in the BAA:

- investigating a range of viable approaches - as in figure 1 and coverage of RFID, pseudolites, and phased array antennas in task 3
- assess the viability, benefits, limitations, and obstacles for different approaches based on technological, business, and deployment characteristics (task 2)
- a test of the most viable approach designed as an integration of complementary solutions (task 3 year 2)

The impact of HALO will be a comprehensive systems approach to laying down a national strategy for the next generation of vehicle positioning infrastructure and the technology for the necessary components on vehicle and roadside.

2. Innovative Claims (optional)

The BAA seeks research to help discharge:

“the federal responsibility is to determine if public sector infrastructure solutions could significantly improve a nationwide [positioning] capability.”

It asks the proposer to focus on “Vehicle-infrastructure cooperation technologies” in a manner complementary to other technologies, in particular the GPS/INS/Vision effort underway at Auburn University. It envisages the investment in this new positioning infrastructure only “in areas that fundamentally cannot receive the critical GPS signals.” Finally it suggests the system engineering process for this new infrastructure give primacy to the requirements of “emerging advanced driver assistance systems” and “applications that require lane level positioning such as intersection collision avoidance, road departure warning, and automated vehicle lateral or longitudinal control.”

Our HALO concept and task plan innovates to deliver on all these objectives. Task 1, on accuracy requirements for HALO gives primacy to the applications emphasized in the BAA. The project PI, Professor Sengupta, led the Cooperative Collision Warning project sponsored by General Motors (10). This project prototyped the first system able to deliver collision warnings on sub-second timescales based on GPS+INS+WiFi (11). All information was derived purely from GPS+INS, with no other sensors such as radar, lidar, or vision. We hold over 60 km of data on GPS based position estimation under different satellite conditions which we will use to determine the system requirements for this project. Professor Sengupta also led the Safety Evaluation work for the National Automated Highway System Consortium that found innovative ways to derive requirements for “automated vehicle lateral or longitudinal control” (20). He is also PI of the CICAS Signalized Left Turn Assist project developing requirements for “intersection collision avoidance” (6).

Discharge of the federal responsibility cited in the BAA requires system engineering on the macro-scale and solution development on the micro-scale. To address the marco-need of the BAA through Task 2 on “Nationwide Positioning Infrastructure Cost Assessment,” we innovate to deliver maps in ArcView showing where the new positioning investment will be required without driving the country. We describe innovative sampling methodologies and modeling using non-traditional data sources such as FAA sectionals and the National Land Cover Database coupled with GPS models. Moreover, task 2 will use the data being produced by our new Safetrip-21 field test led by this proposal PI. The GPS data streaming in from the cellphones of the field test participants will give us direct indications of the dark areas here. Further to deliver a national spectrum plan we innovatively combine DSRC with long-range LMS to target national inter-operability. We can do this due to the expertise of Mr. Warren Havens, President of the Skybridge Spectrum Foundation and part sponsor of this project.

Finally, we propose innovative ideas to execute Task 3: Build and Test the most viable new positioning technology. Task 3 uses pseudolites as its starting point but then proposes to explore augmentation with RFID and angle of arrival measurements exploiting phased array antennas to reduce costs. Professor C. Rizos, PI of our sub-contract to the UNSW, Australia, has pioneered pseudolite technology and advises the Locata Corp, the leading manufacturer of these products. Professor Kannan Ramachandran, Co-PI, is co-Founder of WiRama technologies and co-holder of several of its patents on precise RFID positioning using phased arrays (28)(29). For in-depth expertise on fusing with current GNSS solutions, our team includes Dr. Mohammad Usman, who pioneered leveraging both GPS and Glonas to derive GPS corrections (7), and holds two patents in the area. Moreover, he did this in the context of driving cars while working with Mitsubishi. Enhancing current pseudolites to get a cost-effective working solution using the ideas we propose will require innovative signal processing. Professor Ramachandran and Dr. Usman with their distinguished careers in signal processing equip us with the depth and breadth to move ahead (7)(28). To ensure, a vehicle receiver that will be cheap and viable, our team includes Mr. Ravi Puvvala of Savari Networks. He will be taking leadership in the area of prototyping on software defined radio. Mr. Puvvala has built, according to some, the most economical OBE and RSE for the national VII and DSRC programs. We will be testing under real conditions on the VII California testbed and therefore our team includes Mr. James Misener, the principal architect of the VII California testbed. Their inclusion gives us the experience needed to build something deployable on the vehicle, on roadway poles, and cabinets.

There are two basic methods of multi-lateration. Either one measures distances to a set of reference base stations or satellites or one measures angles. GPS and pseudolites basically do distance measurement. They maintain highly synchronized clocks across the reference stations and derive distance through Time Difference of Arrival (2)(3). Our basic idea is to add positioning based on angle. This is practical today because of the advances in DSP hardware and phased array antennas (4), demonstrated, for example, by the rise of MIMO OFDM (IEEE 802.11n) as a WiFi product. We propose to bring the power of this new class of chipsets to precise positioning (28)(29). Augmenting pseudolites with Angle of Arrival (AoA) estimates derived using phased array antennas should cut cost by significantly reducing the need for highly precise clock synchronization (2) (3) and resolving multipath through angle of arrival measurements (4). Moreover, these methods can also fuse pseudolite systems with RFID readers and tags (29). The power of the AoA approach lies in the ability to combat multipath interference (1). In particular, sophisticated array processing algorithms should allow the receiver to compute the angles of all incoming rays: both the line-of-sight path and the reflected waves (1). Furthermore, by measuring the angles of multiple pseudolites, and collaborating with other receivers, it should be possible to isolate the line-of-sight path, thus reducing the effect of the multipath. If the reflected waves are independent in space, the receiver will be able to deduce which set of angles are consistent with one other, and thus the direct waves. One challenge in implementing phased array antennas is the spacing of the antennas which are in the order of the wavelength of the signal (in the order of ~30cm for 1GHz carrier). This may be problematic if such antennas cannot be integrated in the body of the vehicle or the on board unit. If faced with this issue, we will approach it by leveraging mobility to create a virtual phased array antenna by sampling at different time instances using one moving antenna (28).

As figure 1, illustrates HALO will be built to complement the GPS+INS+Vision systems being built and inter-operate with GPS, GPS+WAAS, GPS+Network RTK. The challenge here is to build an in-vehicle receiver able to operate the multiple RF-front ends and DSP implied by figure 1, i.e., positioning with different technologies in different places, while keeping the receiver cheap. We will approach this challenge by prototyping on software defined radio (8). We have created partnerships with the software radio companies Fullmax and Lyrtech to be on the cutting edge.

3. Vision

Our innovation not simply a device or service; our innovation is more broad. It is our vision – how to enable ubiquitous positioning environment – and it leverages our bona fides in ownership of spectrum coupled with a long-standing understanding of the necessity for high-accuracy positioning as a foundation for ITS applications. We embrace the promise of driver safety but all the while have as additional targets the plethora of other mobility applications. In short, we envision that many spectrum bands and radio services could be needed and will be available for full implementation of HALO and tightly integrated ITS radio communications ("ITSCom").

How do we, in our vision, intend to in the end marry spectrum licensing, ITS applications to include safety and this proposed approach? First and foremost, we offer a straightforward systems approach: examine the problem (year 1), then apply solutions (year 2). Whatever the case, we have a strong, committed public-private-academic partnership to do so. We are willing to 'put our money where our mouth is' and execute the contract. But we keep our eye on the aforementioned vision, target and our pathways. The BAA asserts a federal responsibility to determine if public sector infrastructure solutions could significantly improve a nationwide positioning capability. We have assembled a public-private research team that is highly motivated to produce the means, i.e., the tools, maps, prototypes, and experimental data, needed to make this determination. The products we propose to deliver are conceived to clearly and cogently illuminate the case for a High Accuracy LOcation (HALO) system encompassing the nation's roadways.

As early as 1991, the Intermodal Surface Transportation Efficiency Act (ISTEA) charged the Secretary of Transportation to design and prototype a fully automated highway system able to revolutionize the safety and productivity of the national highway system. The prototype developed vision and magnetic marker based lane keeping as the importance of precise positioning came to be quickly appreciated. In 1995, NHTSA's report to Congress showed that 90% of the road accidents today could be at least partially attributed to driver decision error. Recognizing the opportunity to save lives even without full automation, Congress continued funding NHTSA to enable intelligent in-vehicle warning systems targeted to ameliorate these crashes with real-time driver alerts in critical situations. As these Congressional imperatives bore fruit, the first generation of safety system research prototypes emerged based on sensors such as radar, lidar, and vision systems to detect neighboring cars. It was quickly realized that knowing the roadway environment, such as its geometry, upcoming curves, cars around intersection corners, or signage, was critical to the operation of safety systems. Much of this is beyond the sensor field of view. Research seized upon the idea of mapping all this information and recovering it in real time by precise GPS positioning and map matching[3] GPS-based AVSS became even more valuable, as the cost of sensor based systems came to be better understood, and WiFi started to proliferate. Government and industry came together under the aegis of the Crash Avoidance Metrics Partnership (CAMP) Vehicle Safety Communications to research Cooperative Vehicle Safety Systems (CVSS). In the CVSS concept, potentially a cheap and therefore quick pathway to the saving of lives by getting vehicle safety systems quickly into all cars, each vehicle

[3] http://www.nhtsa.gov/portal/nhtsa_static_file_downloader.jsp?file=/staticfiles/DOT/NHTSA/NRD/Multimedia/PDFs/Crash%20Avoidance/2004/FinalRept_111904.pdf

broadcasts its GPS position and speed to neighboring vehicles. The receiving vehicle subtracts the received position from its own, determines if there is a threat, and informs its driver. Thus getting CVSS into people's cars relies critically on two capabilities – the ability to always, reliably know one's position in the GPS coordinate system, and vehicle-vehicle, roadway-vehicle wireless communication. An entire body of literature, to which this research team has a strong contribution, strongly supports the following thesis: Precise positioning and local wireless communication can save lives.

While USDOT has responded admirably to the wireless communication axis of the value proposition, this research is an opportunity to act energetically on the positioning axis. Through initiatives such as the acquisition of DSRC spectrum, VII and VSCC programs, the department has built national momentum behind DSRC that is today equally powered by corporate America. We see this solicitation and our HALO proposal as an opportunity to seed equal momentum for precise positioning. Safety demands reliability. In this lies the case for federal investment. If the public is to be offered safety through precise positioning, the infrastructure must be reliable and be publicly understood to be gradually growing to be present everywhere. Thus it needs to unfold to a national plan evolved at the federal level.

The promise of ubiquity, in many cases, entails massive investment. Therefore the fundamental research challenge is to discover the means to precise positioning nationwide with moderate investment. The opening of the GPS satellite constellation to civilian use in 1978 spawned a dramatic expansion of the original technology base. Thousands of creative minds found products saleable in the marketplace, to grow the accuracy and reach of this DoD service. The path to realizing the goal with moderate investment lays in a national plan, that brings within its ambit, products from the GNSS market, even while recognizing the matter cannot be left entirely to its invisible hand. Figure 1 illustrates this philosophy and we make it concrete in tasks 1, 2, and 3. There is enough in the current literature to make the case that wireless communications and precise positioning brought together for safety systems, can save lives. Thus the need voiced by the BAA is also critical for the success of the national VII and SafeTrip-21 programs. While the HALO research plan is conceived to primarily address the accuracy and reliability requirements of the safety systems mentioned in the BAA, we see the potential for HALO to play an important role in the current administration's commitment to rebuild and renew the core infrastructure. HALO can accelerate the goals of the E-911 program. E-911 is still far from the accuracy envisioned by FCC. In the longer term, HALO can be a critical enabler for a vision such as Automated Electric Transportation. The convergence of the nation's energy and roadway grids could unleash the greatest jump in productivity seen since the building of the Interstate Highway System and wean the nation off foreign oil. The ability to know position precisely will greatly simplify the problem of designing control systems spanning these two networks.

Our vision is micro and macro-scale research products enabling a build by the current administration. The year 1 vision is research enough for FHWA to seed a nationwide roadway precise positioning standards process much as it did for DSRC in 1998. For the same reasons our prototyping schedule (task 3) is aggressive. The PI knows from experience in the DSRC standards process that the transportation industry will not support a standard based on hardware that does not exist or costs $240,000 per installation as do current pseudolites. Hence the emphasis in tasks 2 and 3 on national cost estimates and the generation of prototypes backed by experimental data.

4. Statement of Work (SOW)

Task Group 1 – Accuracy Requirements on HALO

Task 1.1 – Define ITS Safety Applications GPS Requirements

Our current work in CICAS and previous work developing GPS position accuracy requirements for CCW will serve as the foundation of this task. The outcome of this task will be a matrix of GPS accuracy requirements vs. ITS safety applications. Shladover and Tan (9) have derived the accuracies required in position and speed estimates to produce forward collision warnings, lane change warning, and some intersection conflict scenarios with reasonable accuracy and consistency. Vehicle position control systems require centimeter level position accuracy (19). To the best of our knowledge, reference (9) is one of few to have derived GPS positioning accuracy for some safety applications. However, there is an extensive literature on conventional sensor-based collision warning systems (such as lidar, radar, and vision systems), cooperative intersection collision avoidance system (CICAS)[4], National Automated Highway System Consortium (NAHSC) (20), (21), Crash Avoidance Metrics Partnership (CAMP), etc. We will use results from these programs to validate our GPS positioning requirements. We will examine a broad range of safety applications, e.g., situational awareness, intersection collision avoidance, road departure warning, and automated vehicle lateral or longitudinal control.

Duration: 4 months; Labor Resources: PATH and GSR; Leader: Dr. Raja Sengupta

Task 1.2 – Methodology of mapping high-collision concentration locations

Dr. Chan at PATH has developed a methodology to identify High-Collision Concentration Location (HCCL). This is used to screen for and investigate locations within the California State Highway System that have collision frequencies significantly greater than the base. We will expand to enable a nation-wide survey of HCCL. The product of this task would be a statistical model to detect HCCL that can be used nationwide. The current tool is based on the California accident databases

Duration 6 months; Labor Resources: PATH and GSR; Leader: Dr. Raja Sengupta

Task Group 2 – Nationwide Positioning Infrastructure Cost Assessment

Task 2.1 –GNSS Technology and Business Survey (Year 1)

This task will survey all commercially available GNSS augmentation technologies to improve GPS accuracy. Commercially available technology for GPS, GPS+ WAAS, GPS+NRTK and GPS+INS, and research base results for GPS+INS_Vision (22), Pseudolites, and RFID will be surveyed to come up with an actual assessment of the percentages in Figure 1. The product of this task is a cost performance relationship and trends report showing the various

[4] http://www.its.dot.gov/cicas/index.htm

technologies, their infrastructure estimate roll-out cost, their cost on equipping vehicles and the positioning accuracy achieved by each technology.

Duration: 3 months, Labor Resource: PATH and GSR, Leader: Dr. Raja Sengupta

Task 2.2 – Satellite Visibility Model Development (Year 1)

The 4 sources of structural obstacle data will be gathered and fed into a GIS implementation using ESRI's ArcView Software. Each data source will be a layer in ArvView on top of the US national map at a 30 m resolution. A method such as the Inverse Distance Weighted (IDW) special statistical interpolation method will be implemented in ArcView utilizing the Spatial Analyst extension of ArcView. IDW is a spatial statistics technique used to perform linear combinations of weights at known points to estimate unknown location values. IDW is very widely used as an interpolation method in GIS applications for census, agriculture and other industries and has proved to be a highly cost-effective way of predicting spatial parameters. Most of the work in this task involves spatial data gathering and fusion from different sources of digitized map content and an implementation of IDW. This will serve as the framework for estimating the Mask Angle.

Duration: 6 months, Labor Resource: PATH and GSR, Leader: Dr. Raja Sengupta

Task 2.3 – Road Sampling Strategy (Year 1)

Using the Spatial Analyst extension of ArcView and the IDW we can interpolate an observed data element (in this case the Masking Angle) given the various data layers available at that point. Several sampling techniques can be used with IDW and their contribution to the accuracy of the model has to be tested. We present here three sampling techniques that are also used in GIS application and for IDW interpolations. Those techniques consist of the systematic, random and systematic-random. The systematic method chooses from a certain square geographical area measurements taken at equal intervals of x and y coordinates. The random technique chooses randomly from the square area, and the systematic-random chooses from equal intervals from either the x or the y and randomly from the other axes. We will investigate the 3 sampling methods on 3 varying geographical areas and 3 varying sample densities. Our end result will be the variance of GPS accuracy measurements given the 3x3x3 approaches outlined above and a recommendation for the best approach on sampling technique, same area size and sample density to be adopted nationwide. PATH is currently conducting a Field Operation Test for the FHWA SafeTrip-21 project from which GPS data measurements will be collected for the San Francisco Bay Area; these measurements will serve as a first step in validating the model and sampling strategy and will motivate the decision on implementing the Case Study in Task 2.4.

Duration: 3 months, Labor Resource: PATH and GSR, Leader: Dr. Raja Sengupta

Task 2.4 – Case Study: Sizing the "Dark Area" in the San Francisco Bay Area (Year 2)

Given the model developed in Task 2.2 and the sampling strategy outlined in Task 2.3 we will drive the sampling areas for the San Francisco Bay area and feed them to the model. The model will be calibrated based on sample size, sample region and actual GPS accuracy measurements in those areas. Once calibrated, the IDW interpolation in ArcView will be executed to generate the GPS accuracy map for the Bay Area. Given the results of Task 2.1, we can now subtract the accuracies that can be achieved by a certain investment in commercially available equipment to obtain the "dark area" estimate for the Bay Area. Finally, using the technology solution selected by task 3.2 we will convert this into a cost estimate.

Duration: 9 months, Labor: PATH and GSR, Leader: Dr. Raja Sengupta

Task 2.5 – Develop Spectrum Plan for Positioning (Year 2)

This task will explore spectrum availability and licensing rules for HALO and ITS communications. Skybridge and Telesaurus, our cost-share partner, have offered LMS bandwidth to do the necessary tests proposed in Task Group 3. LMS bandwidth has the advantages of high power and priority for safety. This task will integrate LMS and DSRC for critical point-to-point radio communications in the HALO+ITSCom radio networks, to carry traffic between base station sites, and to network control centers, as well as to provide wireless links to other ITS components such as transportable traffic signs, traffic signals and counters, and video cameras (where there is sufficient capacity). The product of this task is a spectrum plan that ensures nation-wide coverage, reliable (licensed) bandwidth for the short range and long range communications, and interoperable between the short range and long range via the SDR.

Duration: 6 months, Labor Resource: PATH and GSR, Leader: Dr. Raja Sengupta

Task Group 3 – Build and test the most viable new positioning technology (Phase 1 and Phase 2).

Task 3.1 – Experimental testing of RFID and Pseudolites (Year 1)

This task will be the starting phase of the development of augmentation methods for pseudolite and RFID based solutions. As the first step, we will evaluate the performance of the available pseudolite and RFID based solutions through the following two subtasks:

SubTask 3.1.1 Experimental testing of RFID hardware for moving vehicles

This subtask will be carried out by Savari Networks[5], using available RFID based solutions in the market (e.g., from Alien Technology). The objective is to evaluate the performance of the system at highway speeds. VII California facilities will be used for testing the RFID devices on roads (Figure 3). The results of this task will identify the required modifications needed for phased array antenna based RFID readers.

Duration: 6 months, Labor Resource: 50% Savari Networks, 50% UCB GSR, Leader: Ravi Puvvala

SubTask 3.1.2 Experimental testing of pseudolite for moving vehicles

[5] See letter of commitment from Savari Networks

This subtask will be carried out by SNAP lab at the University of New South Wales[6]. The objective is to evaluate the performance of the pseudolite systems for moving vehicles, in particular at highway speeds, to determine accuracy and range. The results of this task will identify the required modifications needed for pseudolite based systems. In particular, the effect of multipath signals will be investigated.

Duration: 6 months, Labor Resource: SNAP lab, University of New South Wales, Leader: Dr. Chris Rizos

<u>Task 3.2 – Specification and simulation of feasible system on vehicle and roadside (Year 1).</u>

Following identifying the technical requirements of each of the augmentation systems, i.e, phased array antenna augmentation of pseudolites and RFID based systems, the system architecture and cost will be evaluated. We will also consider other required enhancements for pseudolites. This task will deliver a specification of the required system, including hardware, software and system level design of the proposed solutions. Specifications of the required hardware for super-resolution sampling and realizing virtual phased array antennas will be completed in this task, through the following subtasks:

<u>Subtask 3.2.1 Algorithm development for precise angle measurement using phased array antenna for pseudolites</u>

This task is carried out at the University of California Berkeley, and will produce the required simulation tools and algorithms for precise AoA measurement. This task will include designing algorithms for multipath mitigation, as well as virtual phased array antennas. Simulations tools are expected to be developed using MATLAB software.

Duration: 6 months, Labor Resource: UCB GSR, Leader: Dr. Kannan Ramchandran

<u>Subtask 3.2.2 Algorithm design for RFID based solutions, based on phased array antenna</u>

This task is carried out at the University of California Berkeley, and will produce the required simulation tools and algorithms for multipath mitigation and AoA measurement in RFID systems. MATLAB software will be used for this purpose.

Duration: 6 months, Labor Resource: UCB GSR, Leader: Dr. Kannan Ramchandran

<u>Subtask 3.2.3 Algorithms development refining pseudolite design for moving vehicles</u>.

This task is carried out at the University of New South Wales, and will produce algorithms and simulation tools for refining pseudolite designs for moving vehicles. This subtask will follow the evaluation of the Locata pseudolite systems at SNAP lab, and will use the result of this evaluation. The simulation tools developed for the refinements designed for Locata pseudolites will allow an early evaluation of the cost effectiveness of the solution.

Duration: 6 months, Labor Resource: SNAP lab at University of New South Wales, Leader: Dr. Chris Rizos

<u>Task 3.3 – Prototype of feasible vehicle and roadside system on software defined radio.</u>

[6] See letter of commitment from UNSW

This task will be accomplished by Savari Networks [7]. The solutions developed in Task 3.2 will be implemented in a SDR platform. We intend to prototype equipment to support both licensed and un-licensed spectrums. Licensed spectrum in the low 900Mhz from Skybridge Foundation will be used. In addition, our SDR system should support operation in the 5.9GHz band dedicated to DSRC, and the 2.4GHz ISM band. The 5.9 GHz band is of importance to this project, since it is free from the interference present in the unlicensed 2.4GHz band. The SDR system will also be designed in a way to accommodate high power transmissions allowed for the license bands (up to 30 watts effective transmit power).

Duration: 6 months, Labor Resource: 50% Savari Networks 50% GSR, Leader: Ravi Puvvala

Task 3.4 – Testing and evaluation of the prototype system on the VII California Testbed.

This task will involve evaluation of the prototype system on the VII California testbed (refer to Figure 3). The testbed facilities will allow access to highways and intersections in the bay area, which will permit evaluation of both RFID and pseudolite based systems. The existing DSRC infrastructure of the VII testbed will be used as part of the test facilities. Testing the augmentation system based on phased array antennas will require installing pseudolites, RFID tags, and readers at specific position along the VII testbed, which will be facilitated by Caltrans. The objective of the tests is to determine the effectiveness and accuracy of the developed systems on highways and roads.

Duration: 6 months, Labor Resource: UCB GSR, Leader: Dr. Raja Sengupta

The Work Break-Down Schedule is included on the following page.

[7] See letter of commitment

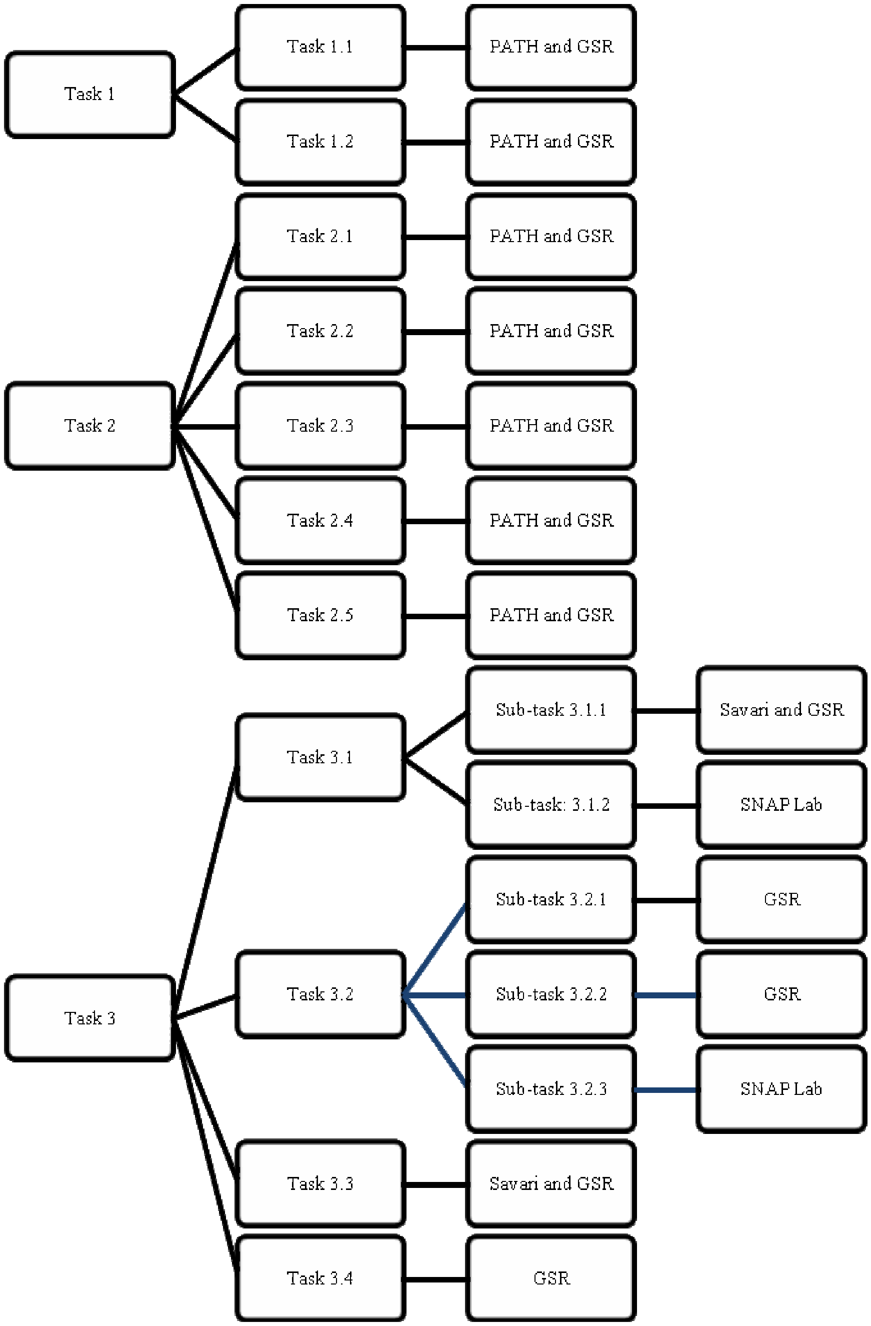
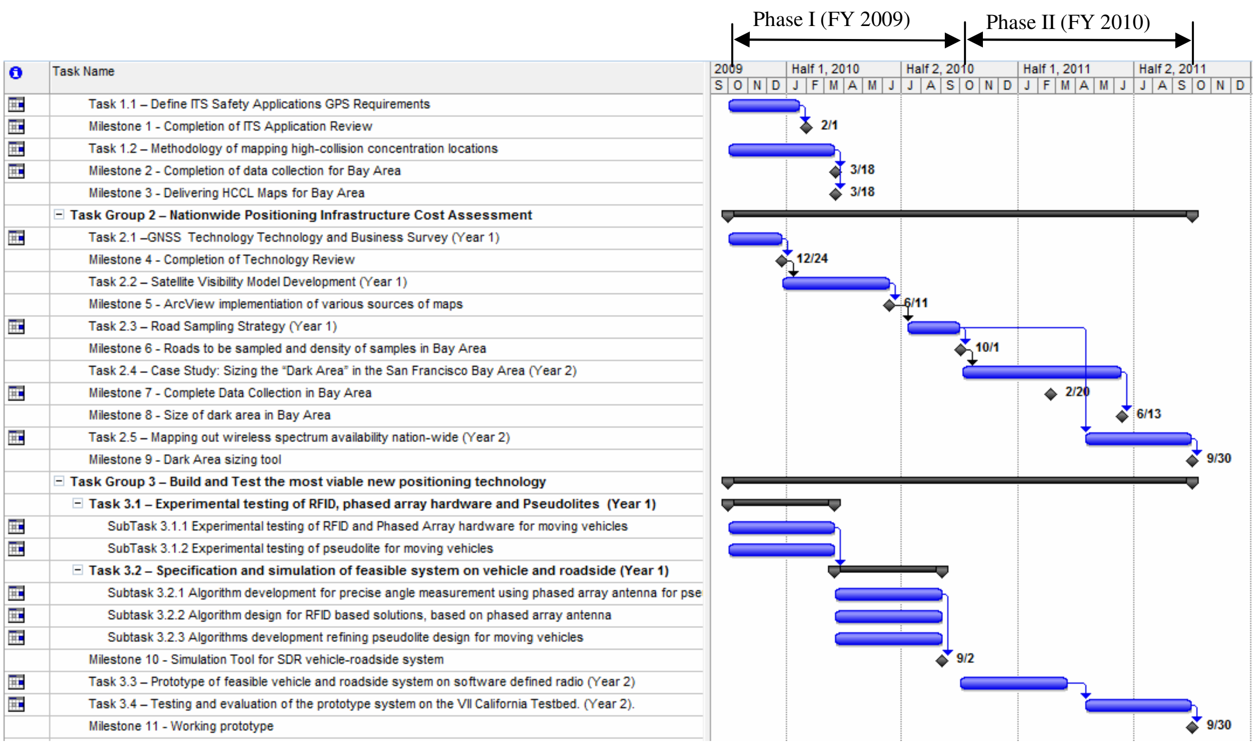


Figure 2. Work Break Down Schedule

5. Schedule, Milestones, and Evaluation Metrics

This Gantt chart shows the schedule of tasks and their dependencies, with numbered milestones indicated as well. The entire work plan is expected to be completed in two years.



See legend on page 1: not for further dissemination.

6. Deliverables and Products

6.1 Deliverables

The proposed deliverables are:

(1) Quarterly progress reports, one month following the end of each calendar quarter

(2) Two project status review meetings per year

Phase 1 Federal FY 2009 (2009-2010)

Task Group 1 Deliverables

(3) Report on result of accuracy requirements for HALO (Task 1.1)

(4) Report describing the methodology to identify high collision concentrations on roadways (Task 1.2)

(5) Case study applying methodology of identifying high collision concentrations on roadways to the Bay Area (Task 1.2)

Task Group 2 Deliverables

(6) Report on GNSS Technology and Business Survey (Task 2.1)

(7) ArcView Software providing an estimation of the dark area tool (Task 2.2)

(8) Report on Road Sampling Strategy (Task 2.3)

Task Group 3 Deliverables

(9) Report on the results of the experimental testing of RFID and pseudolite hardware (Task 3.1)

(10) Simulation tool showing the feasible technology for the dark area adopted for vehicle and roadside (Task 3.2)

Phase 2 Federal FY 2010 (2010-2011)

Task Group 2 Deliverables

(11) Report on sizing the "dark area" and cost estimate in San Francisco Bay Area based on the ArcView tool delivered in Year 1 (Task 2.4)

(12) Report on wireless spectrum availability nation-wide (Task 2.5)

Task Group 3 Deliverables

(13) Software defined radio prototype for vehicle – roadside system (Task 3.3)

(14) Report on results of testing and evaluating the prototype software defined radio (Task 3.4)

6.2 Products

The primary products of this research effort are a set of decision support tools, prototype software and hardware in the hands of FHWA required to estimate the federal investment required for precise positioning on the nation's roads. These deliverables would enable the federal government to assess the benefit of precise positioning, including in relation to high collision concentrations. This will be quantifiable using the deliverables from Task 1, the map of the area to be covered by HALO and cost estimate from Task 2, and the prototype out the strategy for what technology to use in the vehicle and on the road from Task 3.

Furthermore, this research team will actively present its work at leading conferences and publish in the leading journals as well as presenting demonstrations of software, in-vehicle software defined radio systems and roadside units to representatives of the industry and the media.

7. Technology Transition Plan

Our vision is straightforward: HALO+ITSCom technology, once sufficiently developed and integrated (mostly in new generations of software-defined radio, or SDR) will be made available at no charge to both commercial wireless companies and to the major wireless entities including government public safety and service entities and their spectrum bands. These operations can benefit by use of HALO+ITSCom in many ways, for their respective purposes, but even more important, their use will make these ITS more complete and effective. For example, public safety responders and law enforcement will have far better real-time information of accidents and violations on the highways, and pedestrians, bicyclists, roadside workers and others using ubiquitous commercial wireless handheld devices will be able to receive and send warning signals to avoid accidents. Also, we envision that these handheld devices can be docked into ports in vehicles connected to the installed HALO-ITSCom SDR-based communication/computing devices, where the personal ID and other data is automatically ported over to the higher-performance installed SDR unit, and this SDR unit and high performance antenna systems on the vehicle could then use both the commercial wireless spectrum bands and the ITS dedicated bands. There would be, in most all cases and times, HALO+ITSCom radio functions taking place, even if no warnings or instructions to or from the driver is involved; whereas, the use of commercial wireless would be as it is now: by election of the subscriber.

Practical deployment of HALO+ITSCOM is conceived of in several ways. One noteworthy idea is to use public-private-nonprofit partnerships for major US regions, where major electric power utilities serving the region provide much of the network facilities (radio transmission sites, network control centers) and construction and maintenance (they are, more than current commercial wireless companies, in the physical infrastructure business). Many major electric utilities have expressed interest in this concept to our sponsors, Skybridge and Telesaurus. In addition, they are increasingly in the road transportation business, as use of electric drive vehicles expands, and to the degree credible concepts such as V2G (Vehicle to Grid) and AET (Automated Electric Transportation) are put into practice.

Finally, to enable technology transition we have developed partnerships with Locata through its partner SNAP at UNSW, the software radio companies Lyrtech and FullMAx, and the Skybridge foundation – owners of spectrum for high precision positioning nationwide. We are currently engaged in discussions with Trimble and other GNSS companies as well.

8. Facilities

8.1 PATH Headquarters at Richmond Field Station

PATH occupies all or part of eight buildings in the University of California's Richmond Field Station (RFS), hosting approximately about 40 full-time staff members, including program management and administration as well as a core group of research staff members. The Richmond Field Station is a satellite facility of UC Berkeley that primarily houses research units of the University; it is located approximately 10 km from the UC Berkeley main campus. PATH has several research and shop facilities in which to carry out development and testing of automated vehicles, including all the electronic and mechanical tools needed for work on both light-duty and heavy-duty vehicles. PATH also controls an on-site automated vehicle test track approximately 300 m long, which is extremely useful for low-speed testing of experimental vehicles throughout their development. The proximity of the test track to the offices and shop space facilitates rapid development and debugging of vehicle systems. This site also includes the CICAS-SLTA intelligent intersection, equipped with traffic surveillance sensing systems, DSRC communications, and a D-GPS base station.

8.2 VII California Testbed

The testbed provides an opportunity to implement and evaluate different ITS applications eventually leading to significant improvements in the safety and operation of the surface transportation system. The criteria used in site selection include:

- better management and improvement of the safety and productivity of the surface transportation system, and
- covering various infrastructural and traffic characteristics to support research of advance technologies and operational testing towards deployment.

For this project, a stretch of the El Camino Real corridor that connects the City of Santa Clara and Daly City has been reviewed. Fifty intersections have been picked out of 181 signalized intersections on the corridor, as the preliminary selection. The 50 intersections form 2 stretches. The southern stretch connects Santa Clara and Palo Alto, covering 39 intersections, and the northern stretch includes 11 intersections in Burlingame. Figure 3 graphically shows the locations of the two stretches. These 50 intersections cover various types: major/major, major/minor, T-shape and highway on/off ramp, with roadway varying from divided, 6-lane to 2-lane. They also include permitted/permissive left turns from major to minor and minor to major.

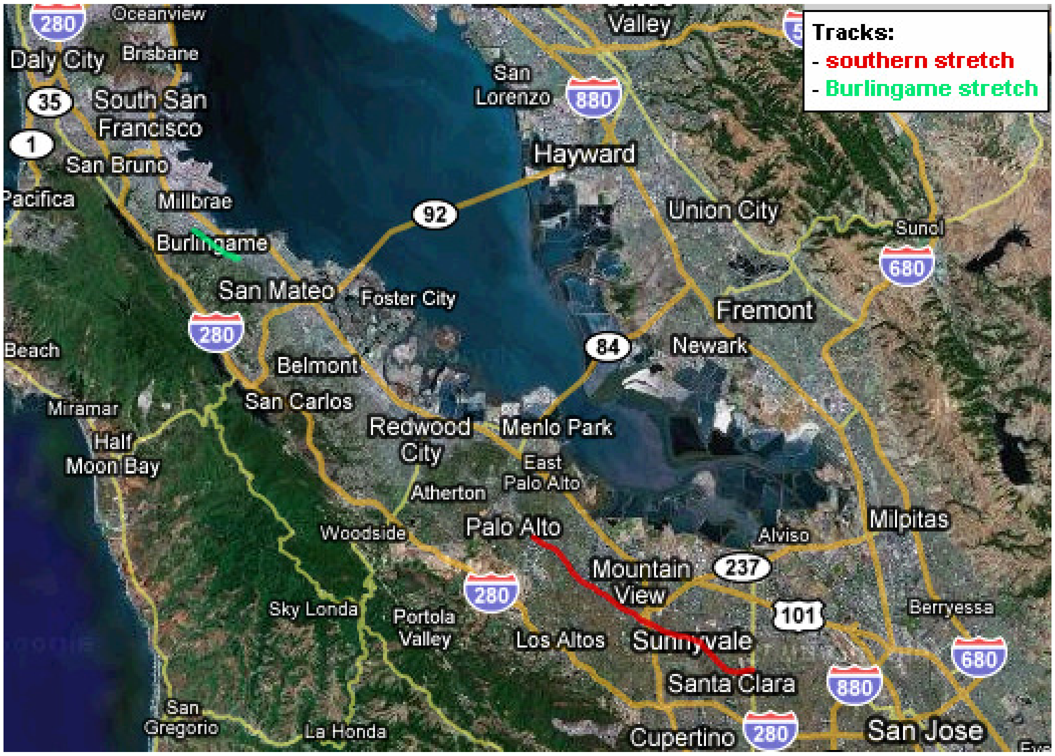


Figure 3 VII California Testbed: Selected Two Stretches

8.3 Wireless Spectrum

12 MHz of M-LMS spectrum is licensed to private companies. Skybridge and Telesaurus, partners of this proposal, hold the A-block M-LMS licenses, 6 MHz of bandwidth in total, in 80% of the nation including most all large markets. They have been for years and remain committed to using this spectrum for HALO+ITSCom and their commitment letter provides for this. 12 MHz adjacent to this A-block M-LMS spectrum is the N-LMS spectrum; it is currently available for licensing to ITS wide-area communication projects, such as envisioned for HALO+ITSCom, where the deployment has participation or sponsorship of a government agency, as we envision for HALO+ITSCom. Combined, this will provide 18 MHz in the LMS band, at the permitted high power levels (30 Watts ERP) and at a mix of high base station transmitter heights in M-LMS (thus, best used for very wide area coverage in many or all directions) and lower heights for M-LMS (best used along major roadways, with directional antennas focusing signal along the roadways). In addition, Skybridge and Telesaurus have obtained from the FCC much of the licensed spectrum in 217-222 MHz in 80% of the US, including most all of the more rural areas, to complement the LMS spectrum for HALO+ITSCom: this lower, 200 MHz range spectrum, at the unlimited transmission heights and hundreds of watts ERP power permitted, will provide especially long range coverage to enable more rapid, full, and cost effective ITS wireless in the majority of the nation which is rural, at least for certain core functions which can be supported by the available bandwidth. This spectrum will be put at the disposal of this project as per the letter of commitment from Skybridge and Telesaurus.

9. Experience

The California PATH Program, which recently celebrated its 20th anniversary, was the first research program on intelligent transportation systems in the U.S. Over the past 20 years, PATH has conducted in-depth research on most aspects of ITS, with particular emphasis on advanced vehicle control and safety systems (AVCSS) and traffic management, the ITS elements that are directly relevant to the proposed research. The PATH research has been based on several governing principles that are applicable directly to the proposed research project:

- Applied research, directed at solving transportation problems, while maintaining the highest standards of technical rigor;
- Combining thorough understanding of the transportation application domain with deep understanding of the technologies to be applied;
- Combining the diverse strengths and perspectives of faculty, graduate students, post-doctoral researchers and professional research and development staff so that each can benefit from the other;
- Providing demonstrations of the technological solutions in action to help stakeholders understand how they work and how they can create benefits to the transportation system.

The PI, Co-PI, and PATH research staff has experience managing large, complicated multi-disciplinary research projects, including some projects larger than the proposed effort, delivering research results within budget and on schedule. In particular, they have worked on challenging projects involving experiments with full-scale vehicles and real-world infrastructure systems requiring extensive hardware and software integration. They know about the need to organize this work carefully and develop risk mitigation strategies from the start, anticipating the many things that can go wrong. This experience is particularly relevant to the experimental work proposed here, since the team for this proposal has already done extensive work on the vehicles and GPS technology that will be used. PATH also has extensive experience in successful demonstrations of ITS, with a nearly perfect record of completely working demonstrations of systems with sophisticated capabilities in the U.S., Europe and Japan.

The PI, Co-PI, and PATH researchers have published the results of their research projects in the leading technical journals and conferences so that the research community as a whole has been able to learn about the outcomes of the PATH research projects. The researchers on the proposal team have published the leading papers in their fields on the topics that are included in this proposal. Space limitations make it possible to include only a sampling of the highlights in the Bibliography and the resumes.

Since its inception, PATH has concentrated on exploratory advanced research, seeking non-incremental advances in transportation. Because of that experience, we are not starting from scratch in defining the national strategy for vehicle positioning. Rather, these are logical extensions of the work we have completed thus far.

10.Qualifications

Dr. Raja Sengupta is currently Asscoiate Professor engaged in the CEE:Systems Engineering Program at the University of California at Berkeley.He was PI of the Cooperative Collision Warning project sponsored by General Motors that developed the first prototype delivering warnings to drivers on sub-second timescales based on GPS and WiFi. He is PI of the CICAS Urban and Suburban Assisted Left-turn System project developing intersection collision warning and of the UC Berkeley Safetrip-21 project. He has also developed the first real-time middleware implemented on 2070 controllers able to meet CICAS real-time requirements for signal control. He led the Safety Evaluation work for the National Automated Highway System Consortium (NAHSC)that set requirements for automated longitudinal and lateral control. He has been a member of the ASTM standard committee on DSRC, Co-Chair of 1st ACM Workshop on Vehicular Ad-hoc Networks, Co-Program Chair of the 2nd ACM Workshop on Vehicular Ad-hoc Networks, and Program Chair of the 1stInternational Symposium on Vehicular Computing Systems. He has been Associate Editor of the IEEE Control Systems Magazine and of the Journal of Intelligent Transportation Systems. He has published extensively on the vehicular wireless communications, GPS and vehicle sensor integration for precise positioning, and advanced vehicle safety systems. He received his Phd in Systems Engineering from the University of Michigan in 1995. He worked briefly for Mitretek Systems.

Dr. Kannan Ramchandran (Ph.D. 1993, Columbia University) is a Professor of Electrical Engineering and Computer Science at the University of California at Berkeley, where he has been since 1999. Prior to that, he was with the University of Illinois at Urbana-Champaign from 1993 to 1999, and was at AT&T Bell Laboratories from 1984 to 1990. His current research interests include distributed signal processing algorithms and communications for wireless sensor and ad hoc networks, multimedia networking, multi-user information and communication theory, and wavelets and multi-resolution signal and image processing

Prof. Ramchandran is a Fellow of the IEEE. His research awards include the Elaihu Jury award for the best doctoral thesis in the systems area at Columbia University, the NSF CAREER award, the ONR and ARO Young Investigator Awards, two Best Paper awards from the IEEE Signal Processing Society, a Hank Magnuski Scholar award for excellence in junior faculty at the University of Illinois , and an Okawa Foundation Prize for excellence in research at Berkeley. His research sponsors include NSF, ONR, AFRL, ARO, and DARPA, as well as industrial research labs such as Microsoft Research, HP Research Labs, Intel Research, Qualcomm, etc. He has co-founded two successful startups in Silicon Valley related to wireless and RFID locationing technologies. He has published over 300 refereed journal and conference articles in his field, holds 8 patents, is actively sought after as a consultant and technical advisor to companies, and has held various editorial and Technical Program Committee positions.

Dr. Chris Rizos commenced research on precise satellite-based positioning techniques at the University of New South Wales, Sydney, Australia, in 1983, focusing on the new Global Positioning System (GPS) technology. Over the last 15 years CI Rizos has built up a strong research team at UNSW known as the Satellite Navigation and Positioning group (SNAP). SNAP is the premier academic wireless and satellite positioning R&D group in Australia, with a strong emphasis on the development of Global Navigation Satellite System (GNSS) receiver hardware, tracking and measurement processing algorithms, as well as the development of non-GNSS based positioning systems using inertial sensors, WiFi and other terrestrial RF-based positioning technologies. The range of projects undertaken by the SNAP group is broad, as can be gauged from the website http://www.gmat.unsw.edu.au/snap/work/our_work.htm.

Pseudolite technology for terrestrial RF positioning is an area pioneered by Chris Rizos. The SNAP group are the only Australian researchers possessing this technology, and since the late 1990s have generated a valuable body of research. This has led to international collaborations with colleagues in the U.K., China, Japan and the U.S. This research has helped *Locata Corporation* (a Canberra company) to develop an innovative commercial product based on pseudolite principles. The Chris Rizos's SNAP group is one of only three university teams in the world researching this new positioning technology, and continues to work with *Locata* to develop measurement processing algorithms. *Locata* has recently been awarded a large venture capital grant for further commercialisation, and the CI Rizos is a member of Locata's Advisory Board.

Current Locata research activities include: (a) the "triple-integration" of GPS, inertial sensors and Locata for precise vehicle positioning, (b) investigations into the use of Locata for precise building/ structural deformation monitoring, (c) RF interference of Locata on/by WiFi operating in the 2.4GHz band, and (d) indoor personal positioning. The research topics range from hardware and antenna performance, signal tracking quality and interference issues, measurement processing algorithms, and integration of Locata with other navigation sensors.

James Misener is currently the Executive Director of the California Partners for Advanced Transit and Highways (PATH) at UC Berkeley. In his thirteen years at PATH, he has led numerous Intelligent Transportation System (ITS) projects at PATH, with sponsorship from US DOT (FHWA, FTA, FMCSA), Caltrans and a host of vehicle manufacturers. For six year, Mr. Misener served as the Transportation Safety Research Program Leader at PATH, where he had oversight with the nearly thirty research projects at PATH involving traffic safety. Since joining PATH in 1995, he has conceived, planned and delivered a host of research projects for Caltrans, US DOT (FHWA, FTA, FMCSA, RITA), several vehicle manufacturer sponsors and the DOD. Many of these projects have addressed the PATH thematic interest in intelligent transportation systems and were molded by Mr. Misener. Some are quite significant: he developed the approach for the first two phases (Intersection Decision Support and Cooperative Collision Avoidance Systems [CICAS-SLTA]) of the California portion of the cooperative intersection safety project, and he currently manages the effort. Recently, Mr. Misener has led the VII deployment test bed in California, which is the foremost such test facility in the United States and served as part of the award of the SafeTrip-21. Mr. Misener currently co-leads the RITA-, Caltrans- and privately-sponsored SafeTrip-21 research effort at PATH, Networked Traveler.

Ravi Puvvala is founder of Savari networks which has a track record of delivering successful networking products for leading multinational companies and startups, Savari is mobilizing Intelligent Transportation Systems (ITS) with cost-effective smart wireless devices that improve roadside infrastructure while connecting vehicles and drivers to the network.

Savari Networks is well versed in building wireless prototypes for many of the research projects in the ITS domain. We have active relations with automotive companies, universities and traffic controller companies. Our R&D prototypes for in-vehicle communications have been used by automotive labs in BMW, General Motors, Volkswagen, Mercedes Benz. We have built on board equipment and road side equipment for SafeTrip-21 program funded by US DOT.

We have extensive experience with various wireless technologies like WiFi, WiMax, DSRC, Bluetooth, GPS. We are working on integrating different various wireless technologies and protocols using software defined radios.

Dr. Shahram Rezaei is a senior development engineer at California PATH. His fields of expertise are signal processing, GPS, Kalman Filtering, vehicular wireless communication, intelligent transportation, and V2V communication. He has more than 8 years of experience in the field of sensor fusion. Dr Rezaei received his PhD in Civil Eng from UC Berkeley in 2008. His PhD research resolved several known and critical problems in the field of cooperative vehicle safety. Prior to PATH, Shahram worked at eRide Inc (a GPS company based in San Francisco that develops high sensitivity GPS receivers) between 2006 and 2008.

Dr. Yaser P. Fallah obtained his Ph.D. and MASc degrees in Electrical and Computer Engineering from the University of British Columbia, Canada, respectively in 2007 and 2001. His graduate research was primarily focused on enabling video and voice communications over wireless networks. Prior to his Ph.D. studies, he was with IBM Canada as a software engineer. He is currently a postdoctoral fellow at the University of California at Berkeley, and is pursuing research in the field of vehicular wireless networking and communications, with applications in vehicle tracking and highway safety.
He has been a member of the Standards Council of Canada committee on MPEG development (ISO/IEC JTC1/SC29) since 2001. He has received numerous awards and scholarships including prestigious NSERC postdoctoral fellowship, NSERC postgraduate scholarship, Bell Canada graduate scholarship, UBC Theodore E. Arnold fellowship, and UBC graduate fellowship\. He is the author of more than 30 refereed journal and conference papers, and is the primary inventor of three pending US patents.

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